NAVAL POSTGRADUATE SCHOOL
Monterey, California

EC 3550 FINAL EXAM 12/93 Po

- This exam is open book and notes.
- There are four problems; each is equally weighted.
- Partial credit will be given; be sure to do some work on each problem.
- Be sure to include units in your answers.
- Please circle or underline your answers.
- Show *ALL* work.
- Write only your name on this sheet.
- Exams and course grades should be available outside the Optical Electronics Laboratory (Bu 224) on Thursday, 16 December.
- Have a good holiday season and enjoy your break!

Course grade: ______________

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| Total | |

Name: ________________________________

**IMPORTANT: Specifications of numbered components are shown in the tables on the last page.**

1. Laser #1 is to be spliced onto a fiber-optic data link. The link has 5 km of fiber #1, 8 splices (not counting the source-to-link splice), and an aging allowance of 3 dB. The extrinsic losses of all splices is 1 dB. The required receiver power to achieve the desired bit-error rate is

$$P'_R[\text{dBm}] \quad = \quad 11 \log\left(B'_R[\text{Mb/s}]\right) - 70 \tag{1}$$

where $P'_R$ is in units of dBm and $B'_R$ is in units of Mb/s.

Find the bit rate that can be supported by this data link.

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2. A 850-nm signal with 9 $\mu$W of power falls on a detector arrangement shown in Fig. 2. The detector is detector #1 operated as a pin detector (i.e., $M = 1$). The preamp has a power gain of 30 dB, an input and output resistance of 50 $\Omega$, a bandwidth of 200 MHz, and a noise figure of 4 dB. Assume that the receiver noise is dominated by thermal noise with a noise temperature of 400K.

Find the bit-error rate that can be supported by this receiver. (Note: you may find it convenient to use the approximation, $\text{erfc}(x) \approx e^{-x^2}/2x\sqrt{\pi}$.)

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Figure 1: Receiver for Problem 2.

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3. Laser #2 is to operate in a 1 Gb/s data link using NRZ coding using fiber #3. The index of the fiber core is 1.45.

Find the dispersion–limited distance for this fiber at this data rate, assuming that the *waveguide* dispersion is the limiting factor.

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4. Consider a fiber amplifier used as a detector preamplifier as shown in Fig. 4. The signal wavelength is 1550 nm and the bit rate is 1 Gb/s. The fiber amplifier has an unsaturated gain $G_0$ of 30 dB, a spectral linewidth of 25 nm centered on 1550 nm, and a $n_{\text{sp}} = 2$. The optical filter has a spectral linewidth of 1.5 nm, centered on a wavelength of 1550 nm. The detector is detector #3, operated as a pin diode (i.e., $M = 1$).

Find the value of the signal power (at the input to the optical amplifier) that will ensure that the electrical noise power in the receiver due to the mixing of the signal and the ASE is 10x the electrical noise in the receiver due to the mixing of the ASE with itself. (You may assume that the saturation power of the amplifier is much greater than the signal power that you are calculating.)

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FIBER SPECIFICATIONS

| | Fiber #1 | Fiber #2 | Fiber #3 | Fiber #4 |
|---|---|---|---|---|
| Size | 50/125 | 62.5/125 | 8/125 | 100/140 |
| $g$ | 1.90 | $\infty$ | $\infty$ | 1.78 |
| NA | 0.15 (at $r = 0$) | 0.20 | 0.11 | 0.18 (at $r = 0$) |
| $\alpha$ @ 850 nm | 4.0 dB/km | 1.0 dB/km | 1.2 dB/km | 5.0 dB/km |
| $\alpha$ @ 1300 nm | 1.0 dB/km | 0.8 dB/km | 0.7 dB/km | 2.0 dB/km |
| $\alpha$ @ 1550 nm | 0.6 dB/km | 0.4 dB/km | 0.4 dB/km | 0.8 dB/km |

SOURCE SPECIFICATIONS

| | Laser #1 | Laser #2 | LED #3 | Laser #4 |
|---|---|---|---|---|
| Wavelength | 850 nm | 1300 nm | 850 nm | 1550 nm |
| $\Delta\lambda$ | 0.5 nm | 1.0 nm | 25 nm | 1.4 nm |
| Power at pigtail end | 0.50 mW | 0.8 mW | 50 $\mu$W | 3.0 dBm |
| Pigtail size | 62.5/125 $\mu$m | 10/125 $\mu$m | 200/300 $\mu$m | 8/125 $\mu$m |
| Pigtail NA | 0.20 | 0.12 | 0.25 | 0.10 |
| Pigtail type | Step index | Step index | Step index | Step index |

DETECTOR SPECIFICATIONS

| | Detector #1 | Detector #2 | Detector #3 |
|---|---|---|---|
| Material | Silicon | Germanium | InGaAs |
| Responsivity A/W @ $M = 1$ | 0.8 @ 850 nm | 0.2 @ 1300 nm<br>0.3 @ 1550 nm | 0.3 @ 1300 nm<br>0.45 @ 1550 nm |
| $C_d$ | 3 pF | 1 pF | 2 pF |
| Excess noise factor | $M^{0.3}$ | $M^1$ | $M^{0.6}$ |
| Bulk dark current | 0.10 pA | 10 $\mu$A | 0.1 $\mu$A |
| Surface dark current | 0 | 1 nA | 0 |

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Figure 2: Problem 4.